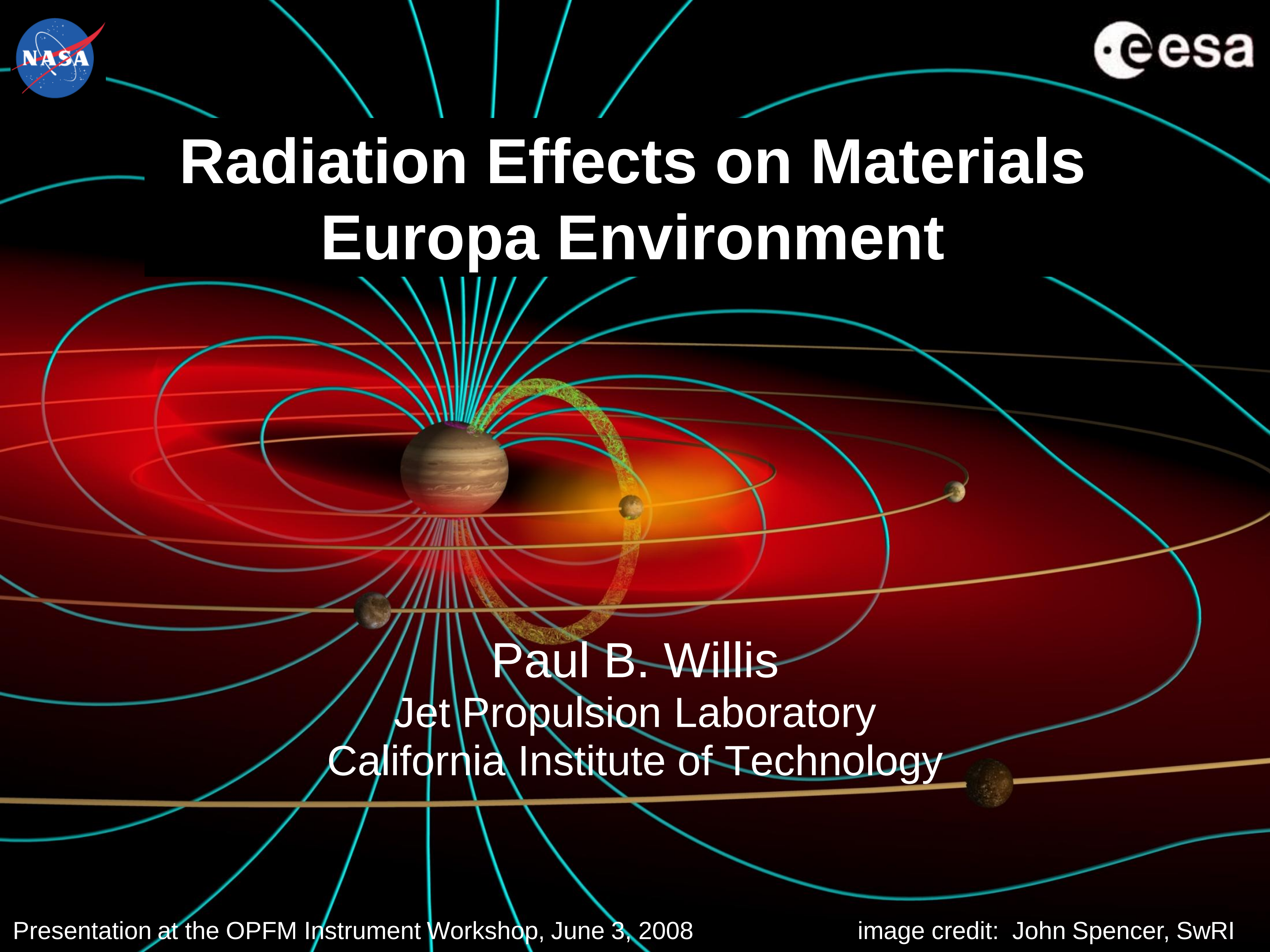

Radiation Effects on Materials Europa Environment

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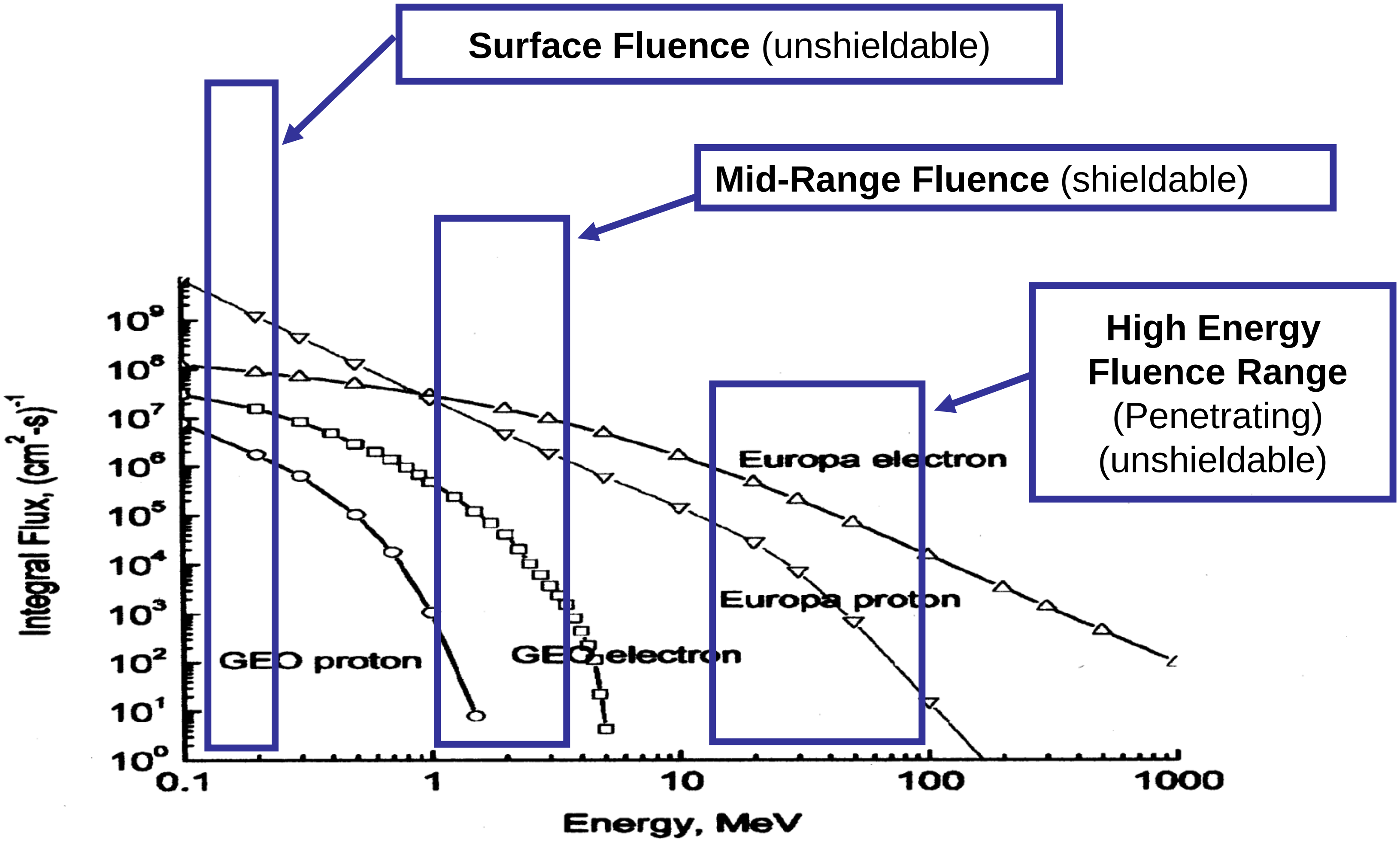
image credit: John Spencer, SwRI

Europa Radiation Environments

- The Europa environment is regarded as “harsh” and consists of a high flux charged particle environment
- Materials challenges include:
  - **(a) high surface doses at low energy**
  - **(b) low doses, but at high energies and long penetration depths**
- The Europa Flagship Mission concept phase; but needs to address radiation issues early to get design data
- Environmental model: GIRE /Divine-Garrett model; mission life 5 years
- Electrons and protons dominate radiation environment
- Electrons and protons up to 100 MeV energy
- Ultraviolet light exposure must be included due to Sun proximity (0.6 Rs)
- As “parts” (electronics) are a special field, this presentation concentrates on <u>materials testing</u> and survival
- The Europa mission will have radiation exposure higher than any spacecraft flown to date

Europa Charged Particle Spectra



Radiation Environment Challenge

- In comparison to Earth (GEO), Europa energies are higher by two orders of magnitude; fluences are higher by one <u>order of magnitude for electrons</u> and <u>three orders for protons</u>
- Each particle type has an energy spectrum that determines the degree of damage as a function of dose
- Electron transport codes not verified in high energy ranges
- Not all particles do the same thing: physics varies as to particle type, energy, dose-depth curve, secondary particles, bremsstrahlung (X-rays), etc.
- Effects: Predominant effects are Total Ionizing Dose (TID) and Displacement Damage Dose (DDD), (mainly protons, and electrons over 0.5 MeV)
- Gammas and neutrons present from Radioisotope Thermal Generators (RTGs)

DAMAGE	Electrons	Protons	Gammas	Neutrons
Ionization	**X**		**X**	
Displacement	**> 0.5 MeV**	**X**		**X**

- **CHALLENGE:** Test and qualify materials for use when environment cannot be simulated in the laboratory, and not all effects can be predicted

Principal Radiation Damage Effects

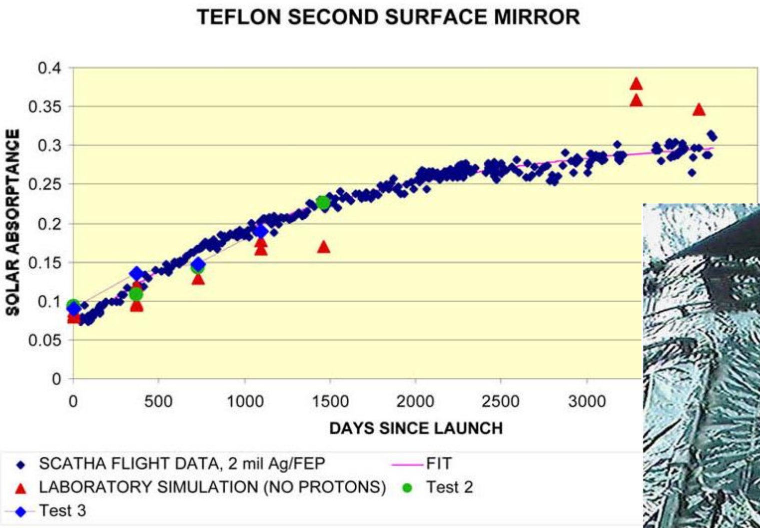
Ionization Damage

- Polymers: crosslinking, chain scission, embrittlement, outgassing, loss of tensile strength, loss of elongation, destruction of elastomers
- Wire and cable: fracture of insulation, loss of dielectric strength, change in dielectric constant, change in impedance
- Lubricants: loss of lubricity, change in viscosity, outgassing
- Thermal control paints: fracture and discoloration
- Optics and glasses: darkening, internal charging, fracture, fluorescence
- Charge accumulation in dielectrics, possible internal arcing
- Ceramics: may cause conductivity, loss of dielectric strength
- Semiconductors: charge deposition, single event upsets (special discipline)

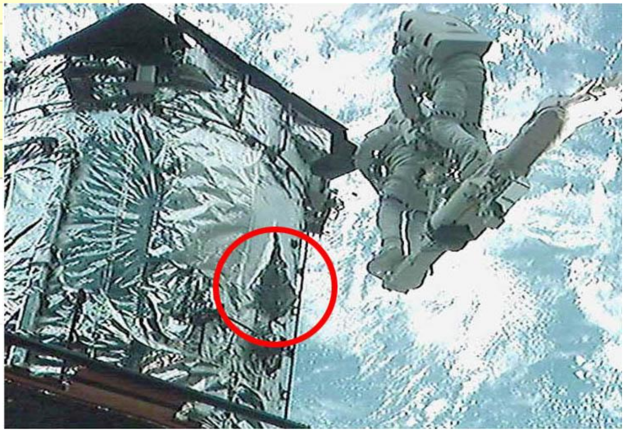
Displacement Damage

- Primary effect is damage to semiconductor devices (junction damage)
- Glasses: density change, refractive index change and discoloration
- Ceramics: fracture, embrittlement, conductivity, density change
- Metals: generally immune, but decrease in tensile strength and yield in some
- Magnets: possible damage to permanent magnets

Radiation Effects on Materials



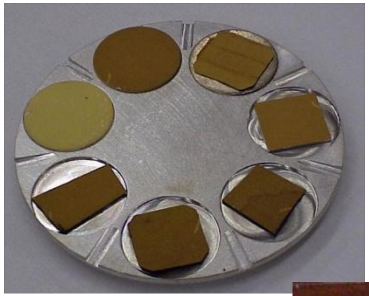
Silver Teflon Flight Data

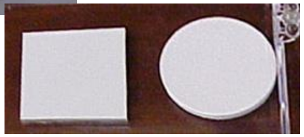


Materials suffer from UV/EUV and particle radiation (Grads on surfaces!) through changes in:

- Dimensions
- Tensile strength
- Conductivity
- Transmission
- Reflectance
- Decomposition

Tedlar: 3-4 Yrs GEO Test Exposure





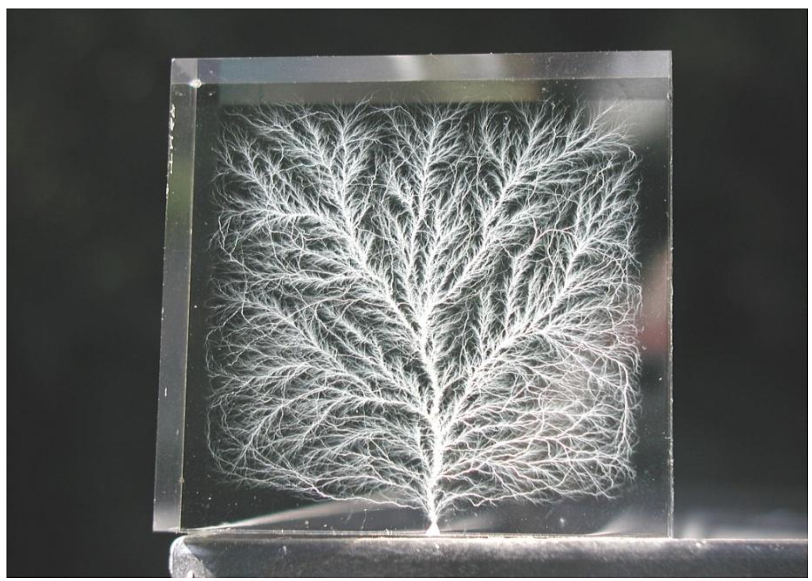
White Paint: GEO Test Exposure

Adapted from Meshishnek et al., 2004
Courtesy of the Aerospace Corporation

Internal Charging Effects

- Internal charging can give rise to catastrophic materials breakdown
- Dielectrics may trap electrons forming “space charge” region at high potential (voltage)
- Insulators may then arc forming a permanent (fractured) low resistance path, and catastrophic materials breakdown
- Electrons may also impart *conductivity*; so <u>lower</u> irradiation rates may be more damaging than very high rates
- Example below: Acrylic, exposed to 4.5 MeV electrons, (Lichtenberg discharge)

60 cm



Current Materials Data

BULK MATERIAL	LIMITING DOSE (Rads)	NOTES
Multi-Layer Insulation	> 1 E +8	Verified data
Polymers	1 E+7 to 1 E+9	Typical range
Adhesives	1 E+8	Typical, always shielded
Composites, epoxy	1 E+8	Onset of change dose
Composites, cyanate	1 E+9	Onset of change dose
Cabling (SPEC 44/55)	5 E+8	Verified data
Lubricants	1 E+6 to 1 E+9	Used in shielded environment
Seals/elastomers	5 E+7	Used in shielded environment
Glasses	1 E+5 to 1 E+10	Depends on composition
Ceramics	1 E+12	Typical value
Metals	1 E+18	Typical value
Fuel (hydrazine)	1 E+6	1% decomposition noted
Note: "Bulk" does not include surface damage		

(All doses are Co^{60} gamma exposure in air)

Gamma Radiation Data
(Literature Data)

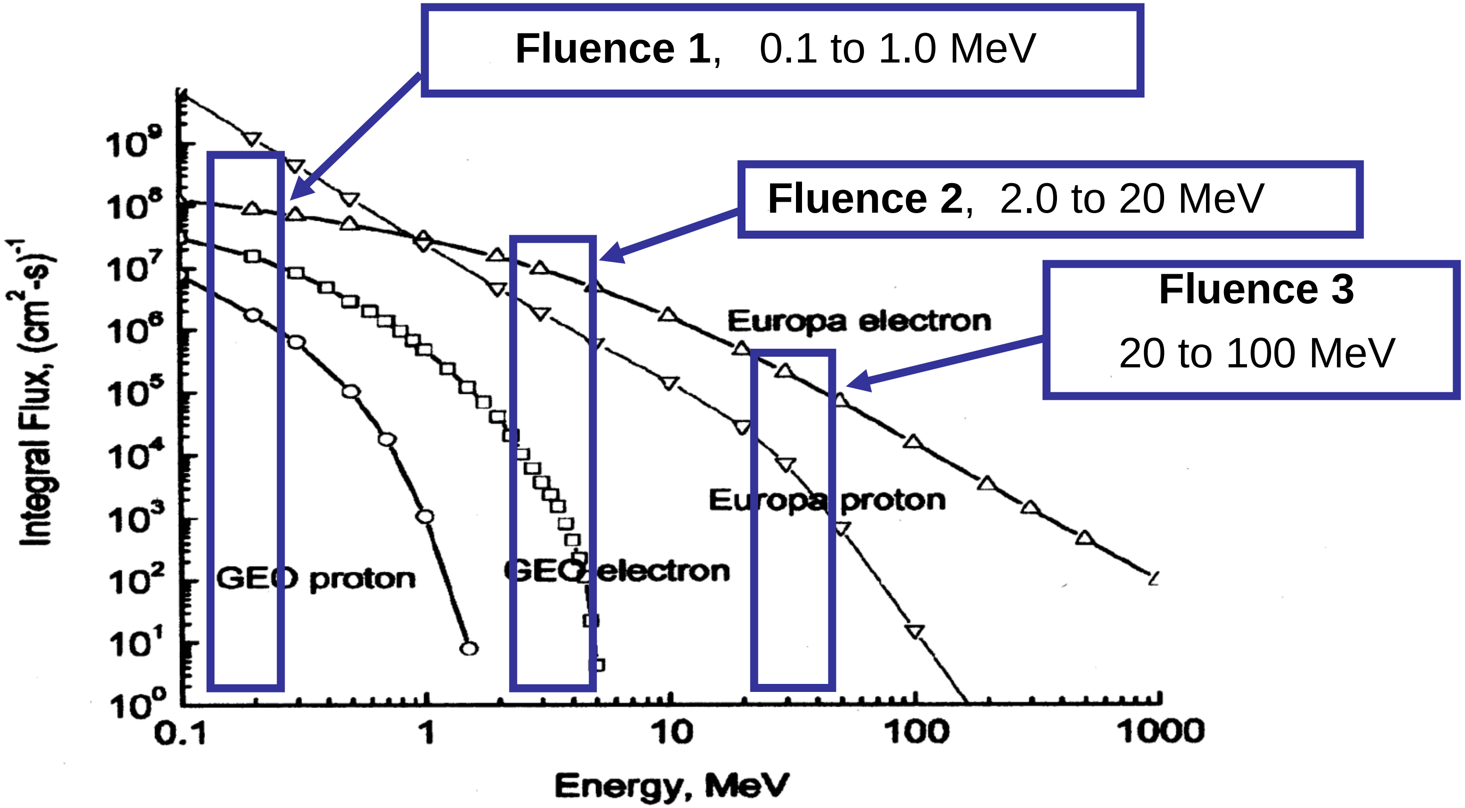
- Most literature data is for gamma exposure in air (not electrons/protons in vacuum)
- Damage dose increases by one order of magnitude in vacuum
- Much data is sixty years old and dosimetry is rarely, if ever, reported (actual dose unknown)
- Many modern materials are not included (eg. PEEK, Kalrez, fluorinated oils, thermal control paints, etc.
- Dose-depth profiles for gammas do not match electron/proton spectra – so surface doses may be much higher for charged particles, and internal doses lower
- Gammas have three modes of physical interaction: (a) photoelectric effect – 0.01 to about 0.5 MeV, (b) Compton scattering – about 0.3 MeV to 8 MeV, and (c) pair formation (electron/positron), 5 MeV to 100 MeV. Ionization is a secondary effect
- Electrons effects are dominated by a single interaction: ionization
- Dose-depth note: At 1 MeV *protons* penetrate approximately 1/100 the distance of the *electron*, and gammas penetrate approximately 50 times the depth of electrons
- Critical properties of interest (dielectric constant, or dielectric breakdown voltage) are not usually measured
- Gamma data has little relevance to space environment conditions (except w/ RTGs)
- Preliminary data from electron exposure shows discrepancies with gamma data

Group Fluence Testing Approach

- Group fluence approach: Expose to discreet energy “bands” of electrons and protons
- Approximate “real” conditions more accurately, and in shorter time
- Damage effects may not be entirely known, but adequate for screening
- Selection of energy ranges also includes the differences in energy effects, including: penetration depth, bremsstrahlung radiation, gamma ray production, Compton electrons, pair production, etc.
- Materials stopping powers, and differing penetration depths results in closer match to Europa dose-depth curves
- Displacement damage (DDD) effects can not be simulated with neutron exposures (mismatch in dose-depth curves) but result from group fluence testing approach
- Testing with electrons and protons should be a closer simulation to Europa radiation environment

Europa “Group Fluence” Testing Scheme

- Expose to total Europa mission fluence of electrons and protons using “group fluence” scheme; assumes that all particles in a range have same energy
- Approach: Select charged particles in discreet energies bands. Three main energy bands under consideration

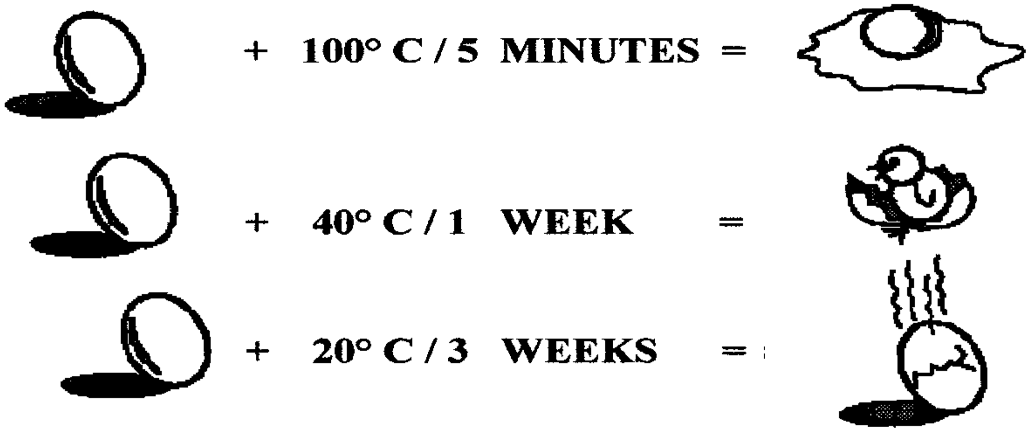


Group Fluence Testing Benefits

- Same charged particles as found in the Europa environment
- Simplified approach that makes practical testing possible
- “Group fluence” approach is not reality, but is available, affordable, practical; provides useful method for screening
- Clear failures and viable components and materials may be identified early in the selection process
- Cost effectiveness: low energy electron testing first (identify non-survivors). Move to more expensive exposures later (protons)
- Sets of specimens can be used for each type of exposure, with one last set that is exposed to all conditions sequentially to represent entire mission fluence
- Identifies materials and regions where shielding may be practical

- Materials under consideration: optical glasses, anti-reflective coatings, multi-layer insulation (blankets), thermal control paints, wire and cable, insulations, composites, adhesives, elastomers, lubricants, and Teflon® type materials

Accelerated Testing - Caveat



First rule of accelerated testing:

- Meaningful acceleration is only possible over ranges of time, temperature, rate and energies where the mechanism remains consistent!
- Equal dose does not necessarily result in equal damage (pathway might be different)
- Beware of dose rate effects – is the physics the same?
- Question your results

Preliminary Test Findings (JIMO Studies)

- A number of “representative” materials were exposed to 4.5 MeV electrons under inert gas
- Teflon® PTFE and FEP maintained usable properties to 2×10^7 rads; three orders of magnitude better than literature values for ^{60}Co gammas in air
- EPDM and silicone rubbers maintained usable properties to 2×10^8 rads; two orders of magnitude better than literature values for ^{60}Co gammas in air
- Kynar® and Tefzel® cable insulations began degrading at 2 Megarads; wire and cable insulations may be at high risk
- Kapton® Torlon®, PEEK®, Vespel®, IR grade quartz, sapphire and epoxy-graphite composites all showed no degradation at 1000 Megarad equivalent doses. Highly stable to electron ionizing environments
- Thermal control paints and blankets may be at the highest risk due to extremely high surface fluence
- Insulators may be at high risk due to charge accumulation

- Preliminary observations: High energy electron exposures in vacuum give very different results than gamma ray exposures in air

Survivability Assessment "Roadmap"

1. Define the mission profile (orbits, cruise stage, final destination, etc.)
2. Determine the radiation environment(s)
   – Particle types, energies, and total mission fluence
   – Include all sources: Van Allen belts, RTGs, free space, final destination
3. Tabulate materials and "map" them to known radiation level locations
4. Identify "exempt materials" <u>not</u> at risk of failure
5. Identify materials <u>with</u> a potential risk of failure
6. Determine needed degree of shielding. Include shielding "credit" from other components such as the spacecraft bus, etc ?
7. Use transport code analysis to determine the deposited dose of the particle type in the material of concern
8. Determine survivability, and assess probable risk of failure
9. Correlate risk with spacecraft heritage: have we flown this before in a a similar environment? Is there a history of success / failure?
10. Test critical materials by group fluence method where necessary
11. If the risk of failure is significant: (a) replace the material with one less prone to damage, or (b) add shielding to reduce dose to acceptable level of risk
12. Remember that the qualification approach is an interdisciplinary process. Ask the experts

Conclusions

- Much materials data is for ^{60}Co gamma ray exposure in air environment, and is 50 years old. Questionable applicability to Europa mission conditions ??
- Although gamma rays are ionizing, damage cannot be realistically simulated due to different dose-depth curves and different physics of interaction
  - **Probably useful for rough screening**
- Preliminary list of radiation effects on materials compiled and available from Europa Project
- Metals, ceramics and carbon composites generally exempt from concern
- Optics and optical coatings require careful selection for survivability
- Polymers, elastomers and adhesives require evaluation
- Thermal control paints, blankets and cabling may be at the highest risk due to high surface fluence
- Insulators may be at high risk due to charge accumulation and arcing
- Materials stopping powers, and differing penetration depths should be tested with a closer match to the Europa mission dose-depth curves
- ***Conclusion: Electrons and protons should be used to determine both ionization and displacement effects as a closer simulation to the Europa radiation environment***
- ***Use "group fluence" testing approach. Start now***

Questions & Answers